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DIFFERENTIAL SENSITIVITY IN GUSTATION [1,2]

HOWARD G. SCHUTZ [3] AND FRANCIS J. PILGRIM

Quartermaster Food and Container Institute for the Armed Forces

In the 88 years that published reports on gustatory differential sensitivity have appeared, only two to our knowledge cover studies on the four accepted primary taste qualities. Keppler (**10**) in 1869 tested the four, but he himself was his only *S*. Trout and Sharp (**21**) reported work in 1937 on all four qualities using four *S*s, but they used ranking and correlation to obtain their measures of sensitivity so that one cannot calculate a difference limen (ΔI) from their data. The literature (**2, 7, 9, 10, 12, 13, 17**) on the Weber ratio ($\Delta I/I$) for taste shows wide variation in the values obtained—the $\Delta I/I$ for each quality differing about tenfold. In addition, the question of the constancy of the Weber ratio has been raised repeatedly, with contradictory answers (**8, 16**).

The present study was designed to determine for the four basic taste qualities at five levels of intensity (I): (*a*) differential sensitivity, $\Delta I/I$; (*b*) the relationship of $\Delta I/I$ to I; (*c*) the relative order of the sensitivities; and (*d*) individual differences in $\Delta I/I$.

METHOD

Psychophysical method.—Pfaffmann (**14**) demonstrated that the method of constant stimuli and the method of single stimuli yield almost identical results. He also concluded that since the method of single stimuli is more convenient than the method of constant stimuli it can be used to great advantage in taste research. Pfaffmann used six stimulus points. In order to determine whether or not fewer points would give comparable results, a preliminary study was conducted in which the method of single stimuli was used to determine the ΔI for .95% sodium chloride. One group of 10 *S*s judged six points and another group of 10, four points. The results were almost identical: ΔI for four points, .10, for six points, .12. Therefore, four stimulation points were considered sufficient.

Next, the concentration interval between the stimulus solutions had to be selected. In order to insure equality of judgment throughout the experiment, one interval was used for all qualities and all levels of *I*. This procedure also allows combining the data across qualities or levels. The interval selected was .15; in terms of a (hypothetical) concentration midpoint (CM) of 1.00, the stimuli, designated 1, 2, 3 and 4, were thus, .775, .925, 1.075, and 1.225 of the CM. The .15 interval is small enough to maintain the attention of *S*, and large enough to cover the anticipated range of sensitivity.

Application of stimulus.—An integrating technique similar to that which Cameron (**3**) recommends was utilized since it appeared to have the least number of objections (**19**) and is also most like normal tasting. Six milliliters of the test solutions were delivered from a calibrated automatic pipette into one ounce "shot" glasses which had been washed and rinsed in distilled water and dried in an oven for 20 min. A previous study (**18**) indicated that 6 ml. was an acceptable amount of solution for *S*s to hold in their mouths (i.e., did not give a

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[2] Part of this material was presented at the 63rd Annual Meeting of the American Psychological Association, San Francisco, Calif., Sept. 7, 1955.

[3] The research reported in this paper is based on a dissertation submitted by the senior author to the Graduate School of Illinois Institute of Technology in partial fulfillment of the requirements for the Ph.D. degree. He is indebted to his adviser Dr. Marion H. Groves for his suggestions and encouragement throughout the research.

feeling of "overcrowding") and was sufficient to thoroughly stimulate the buccal cavity.

Adaptation varies with the method of application of the stimulus. The *S*s were instructed to swirl the test solution around in the mouth and to expectorate and rinse afterwards so as to minimize adaptation. The *S*s differed from one another in their stimulation time from 5 to 10 sec. The period between stimulations was 30 sec. An *S* tested 20 solutions in approximately 15 min., depending on his speed of operation.

There are various techniques and conflicting opinions (**1, 2, 3, 4, 14, 20**) on the most desirable method of rinsing. The *S*s were instructed to rinse their mouths with water in a consistent and natural way after each stimulation, but the amount and number of times were left to their own judgment. Rinsing time varied from about 5 to 15 sec.

Levels of intensity.—Two kinds of preliminary experiments were conducted in order to establish the lower and upper limits of *I* to be tested. These limits were set as the absolute thresholds and the stimuli that were subjectively very strong. Since the lowest and highest levels of *I* are represented by the CM, the actual limits are Stimulus 1, or .775 of the lowest CM, and Stimulus 4, or 1.225 of the highest CM.

The absolute thresholds for the four substances were obtained by the method of constant stimuli with 10 *S*s. The results were as follows: sodium chloride, .089%; citric acid, .004%; sucrose, .35%; and caffeine, .022%. To determine the highest stimuli that should be used, 10 *S*s gave their free comments on three increasingly strong solutions of the four taste substances. The solutions were tested in random order. The value for the strongest stimuli to be tested was chosen on the basis of the comments elicited. The two extremes and the three intermediate levels for each quality were then spaced approximately logarithmically. The midpoint values are shown in Table 1.

The final range of concentrations selected for each of the qualities compares favorably with the most extensive of previous experiments in this area, considering the fact that 6 ml. of solution was used to stimulate rather than one drop as in the work of Holway and Hurvich (**9**). The range is wide enough to both cover the intensities that people experience in everyday life and also adequately test Weber's law.

Materials.—Water for mouth rinsing and preparation of solutions was distilled and then percolated through activated charcoal to remove taste and odor.

C.P. sucrose, sodium chloride, and citric acid, and U.S.P. caffeine were used, each drawn from a single lot for the entire experiment. These compounds are commonly encountered in ordinary eating and also elicit "pure" taste qualities. The materials were weighed to three significant digits and made up to final volume (% wt./vol.). Several times during the experiment the pH of the water was measured and found to remain within the limits 6.0±.3. This small difference would not affect the results.

Subjects.—Ten *S*s, five male and five female, were utilized throughout the experiment on differential sensitivity. They were all volunteers, and were employees of this Institute. They ranged in age from 20 to 58 yr. with a mean age of 33 yr. The *S*s were all practiced in making psychophysical judgments of the type required.

Controls.—All testing was conducted between 3:00 and 4:00 P.M. The *S*s sat in individual booths in an air-conditioned room at 24° C. ± 2°C. and a relative humidity of 35–50%. The *E*s were located on the other side of a partition with a turntable in it through which *E*s presented samples and *S*s transmitted their responses. The samples were of 6 ml. volume. All solutions, as well as the rinse water, were served at room temperature where differences in temperature have little effect on sensitivity (**11, 21**). The *S*s were instructed to refrain from eating, drinking (except water), or smoking for one-half hour before testing.

The *S*s did not know the order in which the qualities and levels of intensity were to be tested, thus minimizing expectation effects. As a check on the possible effects of time, practice, or fatigue, a retest of the first differential threshold, without the knowledge of the subjects that it was a repeat, was run as the last threshold determination.

Procedure.—Each threshold determination consisted of two sessions on consecutive days. At each session the 10 *S*s each made judgments on four sets of test solutions. Each set consisted of the four equally spaced concentrations randomly presented, making a total of 80 responses per stimulus for each level of intensity of each quality. The 20 threshold determinations (five levels for each of four qualities) were tested in a random order with the restriction that one quality could not be tested more than two consecutive times.

All experimental sessions were completed in a period of three months. Missed sessions were made up in their proper sequence.

Next to each turntable was a rack holding four stacks of brass tags numbered 1, 2, 3, or 4. There were always at least six of each number on every rack. Also, in each booth there was a glass of rinse water which *S* could refill.

At the beginning of a session, *S* was informed which quality was being tested. He first received the four solutions one at a time (of the set comprising that day's level of intensity and quality) in ascending order, from 1, the weakest, to 4, the strongest. He was told that this set of solutions was a practice set to acquaint him with the range of solutions and their relative strength. The S then received four sets identical to the practice set but with the stimuli in a random order. This randomization was carried out for each S on every set of four stimuli with the restriction that no S was presented stimuli in the same order for any one of the eight sets of unknowns for each threshold. The S assigned each unknown stimulus a number from 1 to 4 to indicate his subjective estimate of its relative intensity. A number could be used more than once in any given set, but no corrections were allowed; thus the probability of choosing any one number was equal for every solution in the set.

The S tasted each solution by swirling all of it around in his mouth; then he expectorated it into a dental cuspidor and rinsed his mouth. He placed the empty "shot" glass on the turntable along with a brass tag (except for the practice set) and turned the turntable toward an E. At this time the E started timing the interval between presentations. At the end of 30 sec. the next sample was presented. Between each set of four stimuli there was also a timed interval of 30 sec., during which S replaced the tags on the rack.

Treatment of data.—The raw data in this experiment consisted of judgments of 1 to 4 for each stimulus.[4] A judgment of 3 or 4 was scored as a plus. In this way, the number of times out of 8 that a stimulus was called greater than the CM was determined for each of the four stimuli for a given quality, level, and S.

The combining of judgments is possible because the concentration interval for all qualities and levels of intensity is a constant ratio of .15. In this manner an average difference threshold could be computed for any combination of qualities, levels, or people.

For combined judgments the proportions were converted to normal deviates. In two cases of zero proportion the deviates were estimated. For individual data with 8 judgments per point the binomial expansion was computed to obtain the equivalent of the normal deviate with allowance for proportions of 0 and 1. Fitting a line to the deviates by the method of least squares yielded the slope of the line, b, and the variance of the slope, s^2_b (22). The equation of the line can then be solved to yield the point of subjective equality (PSE), ΔI and $\Delta I/I$. By obtaining the ΔI from the PSE rather than from the CM, the ΔI is an average of the lower and upper ΔI's.

The slope, as a measure of discrimination, is inversely proportional to $\Delta I/I$. The use of b is preferable because it has an empirical error, s^2_b, whereas $\Delta I/I$ does not; and this error is uncorrelated with b, whereas the standard error of a proportion, $\Delta I/I$, is a function of the size of the proportion. One disadvantage is that the PSE is not accounted for by b; however, this presents no problem with the present data because of the insignificantly small variations of the PSE from the CM, as is shown later.

The use of b presents one problem that requires treatment of the data to take two forms. The average b based on b's obtained from small numbers of judgments differs from the b obtained after cumulating the judgments as is ordinarily done in psychophysical studies. The average b is generally the larger and leads to the conclusion that the sensitivity is greater than it actually is. However, the 200 individual b's for each quality, level, and S are required for a complete analysis of variance. Therefore, the psychometric values are represented by b's obtained from judgments cumulated over subject, quality, or level. The analysis of variance is based on individual b's. It was demonstrated empirically that analyses of variance of b's based on cumulated judgments and with the error term based on the average s^2_b of the b's in the analysis yield F ratios of the same order of magnitude and significance at approximately the same level as those presented (Table 3). Therefore, it is felt that inferences drawn from the analysis may be applied to the psychometric values presented in traditional form with little risk of error.

Results

The results are reported in terms of the following psychometric values: PSE, ΔI, $\Delta I/I$, and b. The results for the group are given in Table 1. The sequence in which each threshold was determined can also be found in this table. Two general facts are apparent: sensitivity to bitter is poorest at all levels and sensitivity to

[4] The raw data have been deposited with the American Documentation Institute. Order Document No. 5271 from ADI Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington 25, D. C., remitting in advance $1.25 for microfilm or $1.25 for photocopies. Make checks payable to Chief, Photoduplication Service, Library of Congress.

TABLE 1

PSYCHOMETRIC VALUES FOR THE GROUP OF 10 SUBJECTS FOR EACH QUALITY AND LEVEL

Quality	Level	Test Sequence	Concentration Midpoint (%)	PSE	ΔI	$\Delta I/I$	b
Salt	1	7	.150	.150	.0289	.193	.525
	2	10	.400	.396	.0518	.131	.780
	3	2	1.10	1.10	.133	.121	.837
	4	13	3.00	2.98	.357	.120	.850
	5	20	8.00	7.80	1.81	.231	.448
Sweet	1	17	.500	.496	.150	.303	.337
	2	11	1.50	1.53	.221	.144	.687
	3	14	3.00	3.07	.481	.157	.631
	4	8	8.00	7.97	1.23	.154	.658
	5	3	20.0	19.8	2.87	.145	.705
Sour	1	12	.010	.0100	.0029	.290	.350
	2	18	.030	.0303	.0069	.228	.443
	3	1	.100	.101	.0235	.232	.430
	4	6	.300	.300	.0510	.170	.596
	5	16	1.00	1.01	.227	.224	.446
Bitter	1	5	.0315	.0317	.0122	.385	.259
	2	19	.0600	.0607	.0206	.339	.295
	3	15	.125	.125	.0332	.265	.381
	4	4	.250	.248	.0715	.288	.354
	5	9	.500	.503	.124	.248	.406

all qualities is best in the middle range of intensities.

The error of the PSE from the CM (assigned a value of 1.0) was found for each quality and level. The 20 PSE's had a mean of 1.002 and a range from .975 to 1.023 which represents an *SD* of only .5% from the midpoint.

Combinations of the data over levels yielded 400 judgments per stimulus point for each quality and 1600 judgments per stimulus point over all qualities. In Table 2 are the psychometric values for each of the four taste qualities based on data from all levels of intensity and the psychometric values over all qualities and intensities, we might say for gustation as a whole.

Table 3 gives the results of the analysis of variance. The fitting of curves by use of orthogonal polynomials (6) helps reveal where the variation occurs across levels within each quality. Only linear and quadratic effects were considered. Bitter does not differ significantly by level; i.e., the Weber ratio is constant for this quality. For sweet and sour there is a linear slope differing from the horizontal; however, the difference for sweet is due only to poor sensitivity near absolute threshold—the second through fifth levels have essentially the same $\Delta I/I$ or b. In the case of salt, a quadratic curve explains most of the variation. Here again, there is a loss of sensitivity near absolute threshold, but there is also a loss at the highest intensity where the *S*s reported feeling mainly a stinging sensation, in addition to the salty taste. The highest level of bitter and sweet did not give qualitative modulations. The highest level of sour produced some feeling, but this did not significantly affect sensitivity as is evidenced by the lack of a quadratic effect.

In order to locate the between-quality significances found by analysis

TABLE 2

PSYCHOMETRIC VALUES FOR EACH QUALITY OVER ALL LEVELS OF INTENSITY AND FOR ALL QUALITIES

Quality†	Proportion Judged Stronger than CM*				PSE‡	ΔI	$\Delta I/I$	b	s^2_b
	1	2	3	4					
Salt	.142	.442	.638	.840	.993	.152	.153	.668	.0036
Sweet	.192	.378	.565	.832	1.008	.173	.172	.586	.0017
Sour	.240	.388	.622	.722	1.006	.226	.224	.449	.0018
Bitter	.302	.418	.592	.678	1.003	.303	.302	.338	.0008
All Qualities§	.219	.406	.604	.766	1.002	.202	.202	.500	.00014

* 1, 2, 3, 4, refer to concentrations 1, 2, 3, 4 at all levels. Interval was .15 in all cases.
† Based on 1600 judgments, or 400 per stimulus point.
‡ Computed with 1.00 as CM.
§ Based on 6400 judgments.

of variance, a Duncan multiple range test (5) was applied. Bitter (.454) differed from sweet (.856) and salt (1.047) at the .01 level; sour (.611) differed from sweet (.856) at the .05 level and from salt (1.047) at the .01 level; bitter did not differ significantly from sour, nor did sweet differ significantly from salt.

The psychometric values for each subject for the four qualities are shown in Fig. 1.

DISCUSSION

Comparison with previous results.—In terms of order of sensitivity to qualities, from most to least sensitive, the present results differ from the order that Bujas (2) reports—sour, salt, and sweet; and from Kopera (12)—using Saidullah's value for salt—who gives the order as sweet, salt, and bitter. The position of bitter as the least sensitive is the only result that remains constant from experiment to experiment, except for the work of Keppler (10) in which bitter is found to be the most sensitive. In considering the work of Keppler it must be remembered that he used only one *S*—himself.

Of the previous experiments Saidullah (17), Kopera (12), and Bujas (2) found that $\Delta I/I$ was constant over nearly the entire range that was tested, while Lemberger (13), Holway and Hurvich (9), and Fodor and Happisch (7) reported that it was constant only in the middle range. Keppler (10) did not test over a wide enough range to come to any conclusion about Weber's law. Only Bujas, Holway and Hurvich, and Lemberger tested in the area of the absolute threshold.

Another comparison with previous work that can be made is of the actual values reported for $\Delta I/I$ regardless of the levels of intensity that were tested. The present ratio for salt, .15, agrees most closely with the work of Saidullah,

TABLE 3

ANALYSIS OF VARIANCE OF SLOPES

Source	df	MS	F	P
Quality*	3	3.436	15.27	.001
S†	9	1.205	8.55	.001
S-Quality†	27	.225	1.60	.05
S-Level†	36	.243	1.72	
Level within Quality†				
Salt–linear	1	.002	<1	
Salt–quadratic	1	5.091	36.10	.001
Sweet–linear	1	1.254	8.89	.01
Sweet–quadratic	1	.905	6.42	.05
Sour–linear	1	.653	4.63	.05
Sour–quadratic	1	.056	<1	
Bitter–linear	1	.379	2.69	
Bitter–quadratic	1	.000	<1	
Residual‡	8	.187		
S-Quality-Level	108	.141		
Total	199			

* Error term is S × Q interaction.
† Error term is S × Q × L interaction.
‡ Contains cubic and quartic variance for all qualities.

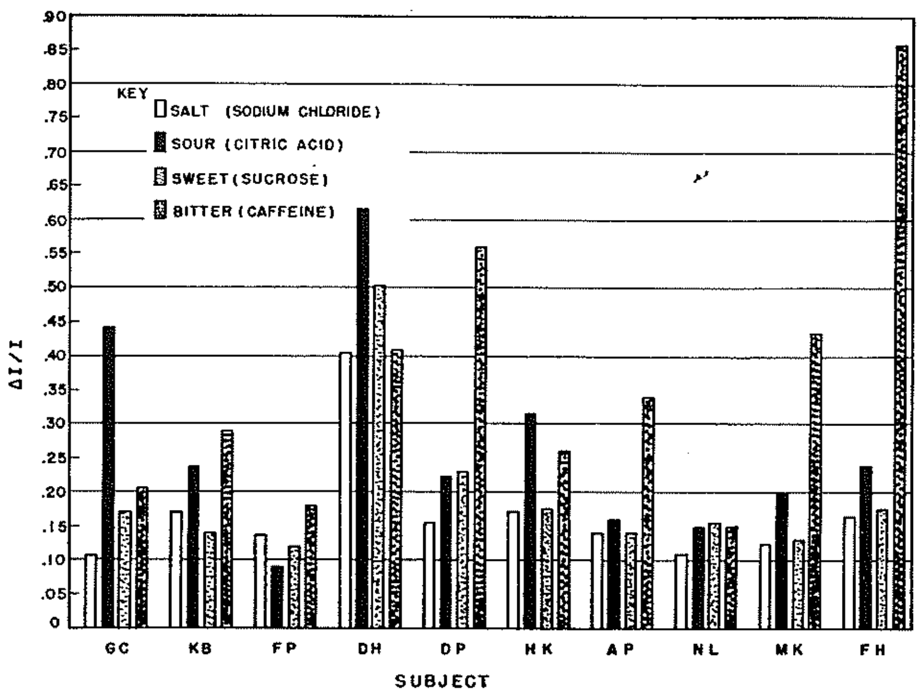

FIG. 1. Differential sensitivity for the four basic taste qualities over all levels of intensity for each of 10 *S*s.

.14, and Fodor and Happisch, .15, and least with the work of Keppler, .67, Bujas, .25, and Holway and Hurvich, .50 (calculated average), with a minimum value of .24. In all these experiments the substance used was sodium chloride, although the purity of the chemical is not stated by any but Holway and Hurvish.

Sour can be compared only with the work of Bujas, for in the only other experiment on sour a different acid was used (Keppler). Bujas' result of .20 is not far from the result of .24 obtained in the present experiment. Keppler found a Weber ratio of .04 for phosphoric acid, a sensitivity that is not at all in line with the present results or those of Bujas.

For the sweet quality the present study yields a Weber ratio of .17. This figure is in close agreement with the results of Lemberger, .20, and with Krogh-Jensen's value of .21, as quoted in (12) and (17), but not at all with the results of Keppler, who used glycerine rather than sucrose, .04, and only roughly with Kopera, .11, or Bujas, .32.

Bitter can be compared with the results of only two *E*s, Keppler and Kopera. In both these experiments quinine was the stimulus for the bitter taste, so comparison with the present study in which caffeine was the bitter stimulus may not be valid. The present ratio of .30 is higher than the .21 found by Kopera and much higher than Keppler's value, .02. The purity of the chemicals was not stated by these two *E*s.

There are several possible explanations for the differences in results between the present experiment and the previous experiments in this area. The first is in the area of psychophysical methodology because the methods differ widely. A second is the range of intensity tested; the present study revealed differences with levels for some qualities, especially at the low and high intensities. A third reason may be the differences in the purity of the chemicals used, or in the case of bitter, the difference between caffeine and quinine. Lastly, the number of *S*s varied from experiment to experiment, a factor which may be of great importance, as is indicated by the individual differences discussed below.

Possible sources of errors.—Practice effects and motivation were studied by repeating the first determination, the third level for sour, at the end of the series, which was three months later, without *S*s knowing that it was a repeat test. The *b*'s and s^2_b's were .430±.069 and .421±.078 and the PSE's, 1.01 and .99. These results have been taken as an indication of the stability of performance throughout the test.

Other factors that could conceivably influence the results are subjective reactions to the solutions either in terms of preference, mainly dislike for some stimuli, especially the strong ones, and also the subjective intensity per se. Therefore, after the main part of the study, *S*s rated, during two sessions, the midpoint concentrations of the 20 sets of stimuli on a 9-interval intensity scale. At another two sessions they rated the same samples on a 9-interval preference scale. In each case, the 20 samples were randomized. There were no significant correlations between group sensitivity and either preference (r = .33) or subjective intensity (r = .11).

There is reasonable certainty, then, that the results are independent of affective reactions to the stimuli, of practice and motivation effects, and of time errors in the method. Postexperimental checks also indicated that none of the stimulus solutions had any odor, so that no errors could have arisen from this source. Although data are limited, there was no evidence of any effect due to age, pH of saliva, or smoking habits.

Individual differences.—In previous experiments the number of *S*s varied from one to eight. As far as could be ascertained there has not been a study in which individual differences in differential sensitivity to the gustatory sense have been determined. In the present experiment it was possible to obtain a measure of the individual *S*'s differential sensitivity by combining his judgments over all levels of intensity for each of the four qualities. The results are given in Fig. 1. Each quality has a fairly normal distribution of *b* values. Bitter has the smallest variation (s^2), then in order come sweet, salt, and sour. From inspection of Table 3, it becomes apparent that there are definite individual differences in differential sensitivity. The analysis of variance shows a significant F for S as a source of variation. This analysis also revealed, by the significant F for the S-quality interaction, that not all *S*s were sensitive to the four taste qualities in the same order. This latter result contributes to the idea of the uniqueness of the four taste qualities. However, an analysis that indicates the extent of the relationship among the qualities are the six correlations, each with an N of 10, between *S*s' *b* values for the four qualities. The only two quality comparisons to approach a significant correlation were between sweet and sour, r = .65. However, they are all positive, the smallest r being .37.

The results on individual differences showed that the highest S variability to the four qualities was for sour. This may be interpreted on the basis of the studies on specific fibers (**15**) which showed that only acid stimulated three types of fibers. It is possible that the greater number of fibers involved in the response to acid, as compared with the other substances, leads to the greater probability of individual differences in sensitivity. It is recognized, of course, that the specific fiber work was done on a nonhuman species and that the human fiber organization for taste may be quite different.

Summary

Differential sensitivity to the four primary taste qualities at five levels of intensity was determined by the method of single stimuli on 10 *S*s. Differences among the differential sensitivities to the four taste qualities are significant. Over all levels, $\Delta I/I$ for salt is .15; for sweet, .17; for sour, .25; for bitter, .30; and for gustation as a whole, .20. Differential sensitivity for

the levels of intensity tested, within each quality, does not differ for bitter and only differs near the absolute threshold for salt, sour, and sweet and near the "terminal" threshold for salt. Individuals differ widely in their differential sensitivity to the basic tastes within the qualities and in the order to which they are sensitive to different qualities.

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